IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)	
Basford, William C.	)	Patent Examiner: Patel, Kiran B. Art unit: 3612
Filing Date: June 8, 2001	)	
Serial No.: 09/877,585	)	January 26, 2004 Hallowell, Maine Zip: 04347
AERODYNAMIC COMBINATION FOR IMPROVED BASE DRAG REDUCTION	)	

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1. INTRODUCTION.

This Brief on Appeal is being filed in response to the Office Action dated May 27, 2003 finally rejecting claims 26 through 29 and 31 through 35 in the above-identified Application.

This Brief is based upon the documents of record on file including an Appendix attached hereto. The Appendix includes the rejected claims, plus additional claim 30, which latter claim is believed to have been erroneously withdrawn by Examiner Patel. The Appendix also includes, for the convenience of the Board, two specific prior art patents relied upon in the final Rejection, plus a limited selection of certain other background art believed to be of assistance to the Board in making its determination.

2. STATUS OF THE CLAIMS.

There are presently at issue a total of nine claims, of which, claims 26 and 35 are independent and the rest are dependent. (Claim 30 is

dependent from claim 27 and thus should be included upon Appeal.) All of these claims are apparatus claims, with claims 26 and 35 being the broadest. Claim 35, in particular, was drafted to define a generic claim encompassing a species (Basford Figure 7) that the Examiner declared was withdrawn from consideration.

The claimed invention was originally defined in a utility Application that was self-filed by inventor Basford based upon two of his earlier Provisional Applications. At the time of first Examination the Application included 13 Figures, 18 original claims, specification of almost 50 pages, 23 non-patent references and 10 patent references. Examiner Patel then added another 29 patent citations in his first Office Action. This body of 62 prior art references - rather than being disabling - is believed to be a strong testimony to the merit, strength and novelty of the invention.

3. STATUS OF AMENDMENTS.

Only one amendment dated March 20, 2003 has been entered. An after final-amendment dated July 26, 2003 and an accompanying Declaration by the inventor, William Basford, were denied entry.

4. SUMMARY OF THE INVENTION.

As the title indicates, the invention is directed to an aerodynamic combination adapted for attachment at the rear end of a truck body in order to reduce drag on the truck body. The invention - a novel combination of vortex generators and shortened boattail plates - significantly reduces base drag; and, thus, improves the "miles-per-gallon" fuel consumption with a minimum of inconvenience to otherwise normal truck operation.

Basford Figure 1 and the inventive vortex generator and boattail plate embodiment of Basford Figure 8 are set forth below.

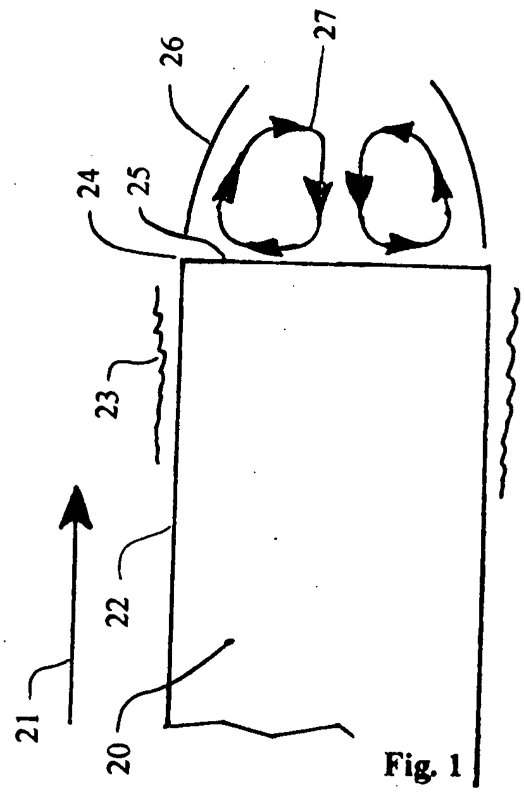

Fig. 1

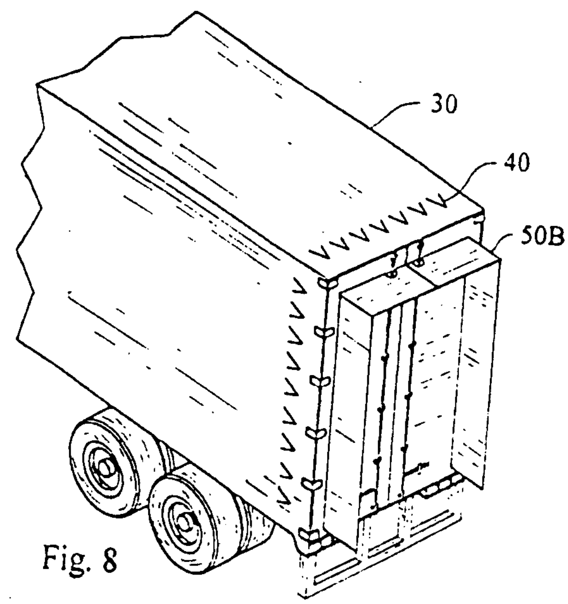

Fig. 8

In this aerodynamic art, fluid-dynamic base drag refers to a phenomenon created at the rear of a body moving through a fluid, which drag hinders the efficiency of the movement of the body through the fluid. Aerodynamically speaking, a bluff body is, by definition, any body where the pressure drag, which includes both forebody drag and afterbody, or base drag, is greater than the skin friction drag. In accordance with this definition, all common highway trucks of the type in the Basford specification are bluff bodies.

As an aid to the Board's understanding, a glossary of terms is included in the Appendix, which glossary fully defines certain terminology necessary for a full appreciation of the invention. The definitions set forth in the glossary are common terms well known to artisans in the aerodynamic art. In some cases, the source for term's definition is set forth as well.

It will be shown herein that Basford has invented a new and novel combination that has significant advantages over all of the known art. The art pointed away from what Basford has done. His vortex generator and boattail plate combination has the unexpected results that it:

- Provides greater base drag reduction than the prior art while at the same time allowing almost conventional truck operation with less rear truck door obstruction.

- Shortens the boattail plates by over 50% of the prior art rearward extension length compared to that when such plates are used alone.

- Achieves this greater base drag reduction without requiring added vehicle length or conflicting with current U.S. regulations for trailer underride bars.

- Provides greater base drag reduction with the addition of a simple device that is easily installed on existing semi-trailer and other trucks.

5. ISSUES.

5.1 Can a meritorious invention be defeated by an Examiner's action in ignoring the critical difference between boattail plates and other prior art boattail types?

5.2 Should specific and material limitations in claims which point in a direction opposite from the art, be disregarded in favor of prior art that admittedly lacks any suggestion for the inventive combination?

5.3 When one reference totally lacks disclosure of a key element of the claimed combination invention, should that reference be arbitrarily merged with the disclosure of another prior art reference when neither reference suggests that their disclosures might supplement each other?

5.4 Can a commercially viable breakthrough invention be defeated by an Examiner's simple unsupported assertion of obviousness without specifying how or why the references should be merged together against the claimed invention?

6. GROUPING OF CLAIMS.

The final rejection grouped all of the claims together and stated that "Claims 26 - 29, 31 - 35, <u>as best understood</u>, are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicant regards as the invention. There is presently pending a Petition for Reconsideration under 37 CFR 1.181. That Petition was submitted on November 25, 2003 and the Glossary of Terms of the Appendix and supporting comments will shortly be submitted in a Supplement to that Petition.

The final rejection also rejected all "claims 25 - 29, 31 - 35, as best understood, under 35 U.S.C. 103(a) as being unpatentable over Switlik '059 in view of Wheeler '837". Claim 30 is dependent from Claim 27 and it is believed that it should also be included on Appeal.

Both the 35 U.S.C. 112 and 35 U.S.C. 103(a) rejections are dealt with in this Brief on Appeal. We submit that the obviousness rejection is in error since the references do not teach or suggest the claimed invention; and, it is also submitted, that the claim language is clear, unambiguous and properly defines the novel combination of vortex generators and shortened boattail plates, which combination Applicant believes is his invention.

7. ARGUMENT.

Dealing first with the 35 USC 103(a) final rejection, the Examiner admitted that one reference - Switlik '059 - does not disclose a plurality of vortex generators. But, the Examiner continued, Wheeler '837 does disclose a plurality of V shaped vortex generators, and "it would have been obvious to modify the Switlik device to include a plurality of vortex generators as disclosed by Wheeler '837, to achieve the desire[d] level of base drag reduction for the bluff body".

Highly summarized, the Basford breakthrough in the art has been presented in the drawing. The background discussion centers around Figure 1, while the inventive vortex generator-boattail plate embodiment is described with respect to Figure 8.

Figure 1, above, is a schematic plan view of the rear end of a bluff body 20, with an arrow 21 showing the direction of fluid flow. Such flow includes boundary layers 23 which form along the side surfaces 22, and

become the separated shear surfaces 26 after passing the trailing edges 24 of the truck body. The flow pattern includes the closed arrow-headed recirculation bubbles 27 - also known as low pressure wake - which wake forms behind the base surface 25. Vortex generator arrays 40 (See Figure 8) cause the separated shear surfaces 26 to turn sharply inward thereby reducing the size of the low pressure wake 27.

In his specification at page 12 lines 7 through 10, Basford states:

> In simple terms, vortex generators energize the relatively slow moving fluid in boundary layers, helping it turn inward more quickly behind the trailing edges of a bluff body.

Placing a rear edge of the boattail plates 50B (Basford Figure 8) at the outer perimeter of the low pressure wake, provides maximum fluid-dynamic base drag reduction for the truck body 30. <u>This stated positioning of the rear edge in combination with linear arrays of vortex generators is critical to the Basford invention and is nowhere taught or suggested by the prior art.</u> (Please see paragraphs 7 through 9, 12 and 16 of the Basford Declaration dated March 19, 2003.)

Claim 26 is a generalized case for a bluff body moving in a fluid, whereas claim 27 is more specific to a truck body moving in air.

26. Apparatus for reducing the fluid-dynamic base drag of a bluff body moving through a fluid and creating, at the rear of the body, a low pressure wake having an outer wake perimeter, which bluff body has a substantially flat rear base surface, a pair of opposed side surfaces, and opposed top and bottom surfaces all joined with said rear base surface at side, top and bottom trailing edges, respectively, so as to form a box-like container, said apparatus comprising:

means positioning side-by-side vortex generators in a linear array ahead of the two side, top and bottom trailing edges of said bluff body for

generating counter rotating stream-wise vortices in a fluid boundary layer passing generally along said bluff body and creating from said layer separated shear surfaces which turn sharply inward aft of said trailing edges;

four boattail plates inset and affixed a predetermined distance from the top and side trailing edges; and

rear edges on said boattail plates sized to intercept the separated shear surfaces of said fluid layer at the outer perimeter of the low pressure wake, thereby providing maximum fluid-dynamic base drag reduction for said body.

27. The apparatus in accordance with claim 26 wherein the bluff body is a land vehicle moving in air, which vehicle has only three boattail plates attached adjacent the top and opposed side trailing edges; and

three linear arrays of vortex generators, one array each associated with one each of said boattail plates.

Claims 26 and 27 were questioned by the Examiner who asserted - numbers three and four, notwithstanding - that:

> It is not clear between claim 26 and claim 27 whether applicant is claiming three or four <u>boattails</u>. (Emphasis Added.)

It is highly instructive that Examiner Patel failed to appreciate the difference between "boattails" and "boattail <u>plates</u>" as described and claimed by Basford. The two structures are not the same, and Examiner Patel mistakenly glossed over the fact that Basford claimed boattail <u>plates</u> - not boattails.

The Basford specification clearly set forth and explained the distinct differences between Full Boattails, Truncated Boattails and Boattail Plates. The Examiner stepped into grave error right from the very

beginning when he concluded: either that boattails and boattail plates were the same thing, or that Basford was claiming boattails. In either event the Examiner was mistaken.

In his March 27, 2003 Declaration, inventor Basford, in paragraph 8, stated clearly and succinctly what his invention was by referring to shortened boattail plates. In Paragraph 8, Mr. Basford states as follows:

> I acknowledge that both vortex generators and boattail plates were known in the art prior to my invention and I have so stated in my patent application. My invention differs from such art and may be summarized as a new and novel combination of vortex generators together with shortened boattail plates at the rear of bluff bodies with the size and positioning of the boattail plates providing greater base drag reduction, while reducing the optimum length or rearward extension of the boattail plates.

The Examiner failed to appreciate the significance of the Basford Declaration. Indeed, at no time in his written rejections, did the Examiner ever acknowledge the Basford Declaration or the various patentability arguments presented by counsel. As far as the record shows, it seems reasonable to seriously question if the Examiner even read them.

Then to top it off, the Examiner did not make reference to the closest prior art and failed to enter into any discussion concerning the nature of the prior art. It appears he selected 2 references from among 62 and arbitrarily combined them in order to get the Application off his desk and out of the way. It is respectfully submitted that the job of the Patent Office is to give a thorough examination in return for the fees paid by an

inventor, and then issue a patent if an extensive investigation shows that a patent is warranted. None of that happened here.

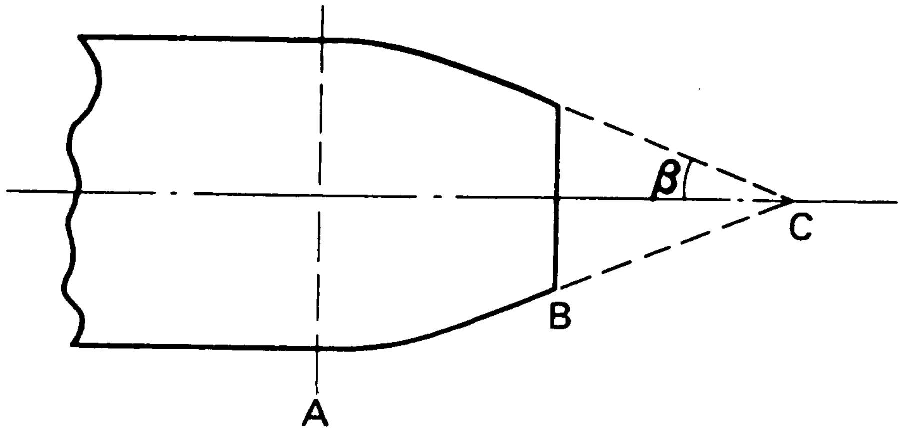

Fig. 5. Boat-tailed afterbody (Mair, 1969).

Set forth above is Figure 5 from a paper by W.A. Mair, entitled Drag-Reducing Techniques for Axi-Symmetric Bluff Bodies, showing a Truncated Boattail. The solid line portion AB of the Mair Figure 5 is a typical boat-tailed afterbody, terminating at a blunt base at section B. If the boattail structure were to continue along the dashed lines to point C then it would be a full boattail terminating at a point. In either event, however, it is clear that this Mair structure is of very little practical significance to the trucking industry.

Mair is one of a limited number of prior art references that sought to use vortex generators with boattail afterbodies. In his lengthy treatise, Mair concluded at page 177 as follows:

> [I]t may be useful to consider whether some form of boundary-layer control (BLC) could be employed...

> The easiest form of BLC to apply to a road vehicle would be a set of vortex generators, although this may be unacceptable for various practical reasons including safety. Experience with aircraft and other applications suggests, however, that even the best arrangement of vortex generators would have only a marginal beneficial effect, and it seems likely that the best boattailed afterbody using these devices would only be slightly better than one without them. (Emphasis Added.)

Although the prior art has steered others away, Mr. Basford dared to try; and, by going against those recognized in this field, the inventor Basford has shown them wrong. The Examiner's rejection should be withdrawn and a patent should issue.

Regarding boattails, Applicant's specification commencing at page 7, line 1 and continuing unto page 8, line 20, states in part:

> Therefore the primary drawback of full boattails is that the maximum drag reduction requires extreme length, often three to four times the width of the bluff body, making full boattails impractical for highway vehicles.
>
> x x x x
>
> [F]ull boattails terminating in a point or narrrow edge are rarely used.

At another specification heading at page 9, line 23, Basford set forth Boattail Plates and devotes over two pages to the development of such structure.

Figure 5 of the Basford specification is set out below. Figure 5 represents a prior art Figure showing the rear end of a typical full sized semi-trailer truck body 30, with three full length boattail plates 50 of the type disclosed by A. J. Bilanin in U.S. Patent No.: 4,682,808.

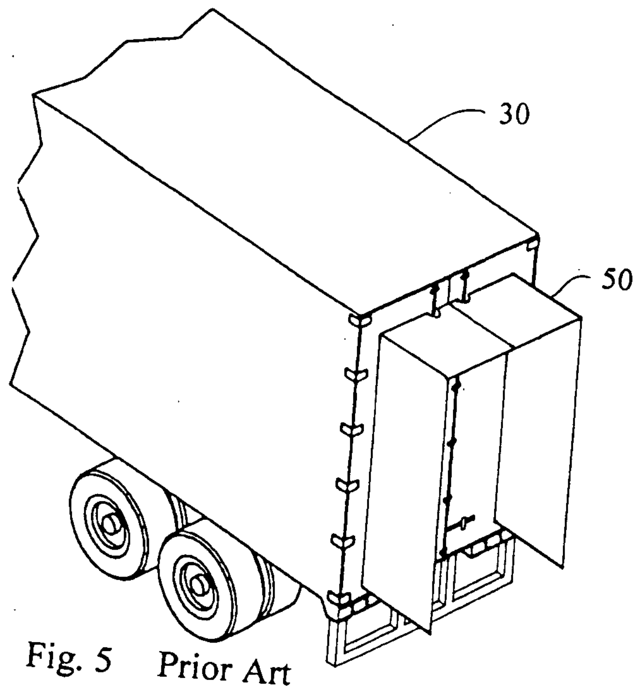

Fig. 5 Prior Art

According to Bilanin the minimum preferred length of these plates 50 should be forty (40) inches. Whereas that may be true for Bilanin's Boattail plates when used alone, Basford has determined that it is not true when Boattail plates are used in combination with low drag vortex generators. Such boattail plates can then be shortened by over 50% to a rearward extension length of about 1/6th the width of the bluff body, or shortened to about 17 inches for a typical full sized 102 inch wide semi-trailer body.

Claim 35 expresses this shortened boattail plate aspect of the combination invention of Basford in wording that is clearly allowable over all of the known art. It reads as follows:

35. Apparatus for reducing to a minimum the fluid-dynamic base drag of a bluff body moving through a fluid passing generally along said bluff body and creating, at the rear of the body, separated shear surfaces which define a low pressure wake having an outer wake perimeter, which bluff body has a substantially flat rear base surface with given height and width dimensions and a periphery of trailing edges, said apparatus comprising:

vortex generator means mounted adjacent to and forward of said trailing edges for generating counter-rotating stream-wise vortices in said fluid layer, which generators cause the separated shear surfaces to turn sharply inward thereby reducing the size of the low pressure wake, and

edge means coupled to said base surface and inset from said trailing edges for intercepting said separated shear surfaces at the outer perimeter of said low pressure wake, namely, at a distance behind said base surface of about 1/6th to 1/8th of said given height or width dimension, whichever is less. (Emphasis added.)

Examiner Patel apparently has little or no working knowledge in the field of the Aerodynamics of Bluff Bodies, and is unfamiliar with the standard terminology used in this art field. For example, in his second Office Action of Sept. 24, 2002, starting on the fifth line from the bottom on page 7, he made the statement:

> It is not clear what is claimed as invention because elected Fig. 8 contains a truck body not a bluff body. The truck body has six (sides) flat base surfaces not one.

Anyone familiar with this art, however, would surely know that a truck body is a bluff body, and that, in terms of aerodynamics, the base surface is always the rearmost surface of the bluff body.

It is additionally enlightening to see the Examiner's statement on page 5 in the Office Action of May 27, 2003, where it is stated that:

> Claims 26 - 29, 31 - 35 as best understood, are rejected under 35 U.S.C. 103(a) as being unpatentable over Switlik '059, in view of Wheeler '837."

This is essentially the same rejection earlier given by Examiner Patel in the first Office Action. In response to that first rejection, Applicant Basford prepared his Declaration under 37 CFR Section 1.132 which pointed out, among other things, that the boattail plates shown in Figs 1-17 of Switlik '059, clearly fall within the scope of Bilanin '808, and that the only new material asserted in Switlik '059 deals with the manner of folding and unfolding the full length boattail plates in order to make them easier to use.

Mr. Basford, a Registered Professional Engineer, licensed in Maine and Vermont, states as follows at paragraph 15 of his Declaration:

> Such Switlik plates, in my opinion, simply follow the Bilanin '808 approach. ..... Switlik discloses an improved way to more easily fold and unfold the boattail plates to allow access to the rear doors of a truck body. Switlik '059 provides no additional base drag reduction over Bilanin '808, and <u>does not suggest any reduction of the optimum length of the boattail plates</u>. Switlik '059 <u>does not teach or suggest that vortex generators can be used in combination with shortened boattail plates to provide greater base drag reduction</u>. (Emphasis added.)

This sworn testimony by Engineer Basford was never commented on nor considered before the 103(a) rejection was made final. One can look in vain throughout Switlik and never find any suggestion therein relating to any of the advantages of the Basford structure nor his inventive

concept. The final rejection is unsound, and a patent most surely should issue.

In his rejection under obviousness, on page 4 of the Office Action dated May 27, 2003, Examiner Patel also additionally made an offhand comment about base drag when he stated:

> Therefore, it would have been obvious to ... modify the device, as disclosed by Switlik '059, to include a plurality of vortex generators, as disclosed by Wheeler '837, <u>to achieve the desire[d] level of base drag reduction</u> for the bluff body." (Emphasis and matter in brackets added)

The desired level of base drag reduction is <u>obviously the maximum possible</u> base drag reduction within legal limitations and other practical constraints such as cost and ease of use for highway vehicles.

The subject invention provides roughly 50% greater base drag reduction than either Bilanin's full length boattail plates or Wheeler's low drag vortex generators when used alone. (Please see Mr. Basford's Declaration paragraph 9.) It does so while simultaneously reducing the optimum length of the boattail plates by roughly half. Neither Bilanin, nor Switlik, nor Wheeler disclose this combination nor the increased benefits in base drag reduction. Indeed, none of these references make any suggestion that the novel Basford combination of vortex generators and shortened boattail plates is possible, much less highly desirable.

Section 706.02(j) of the Manual of Patent Examining Procedure (MPEP) sets forth the mandatory criteria for applying a 35 USC 103 rejection. Such criteria are totally absent in the final rejection of this case. <u>Graham v John Deere Co.</u>, 383 U.S. 1, 148 USPQ 459 (1966) is

controlling, but the Graham rationale was never followed in finally rejecting the Basford invention. The Examiner should have - but did not - set forth:

A. the relevant teachings of the prior art relied upon, preferably with reference to the relevant column or page number(s) and line number(s),

B. the difference or differences in the claims over the applied reference(s),

C. the proposed modification of the applied reference(s) necessary to arrive at the claimed subject matter, and

D. an explanation why one of ordinary skill in the art at the time the invention was made would have been motivated to make the proposed modification.

Perhaps because of workload - or other reasons not apparent from the record - the above-noted guidelines A through D were ignored in this case. In particular, we are left wondering why one of ordinary skill in this art would have combined Switlik and Wheeler. One thing that is very clear, however, there is absolutely nothing in either Switlik or Wheeler that suggests the disclosures of these references should be combined.

Mr. Basford, in paragraph 11 of his March 19, 2003 Declaration forcibly stated as follows:

> It is my technical opinion that these references [Switlik and Wheeler] lack any instructions that would direct one of ordinary skill toward my invention. (Matter in brackets added.)

The initial burden is on the Examiner to provide some suggestion for the desirability of doing what the inventor has done. The case of Ex

Parte Clapp, 277 USPQ 972, 973 Bd. Pat. App. & Inter. 1985) summarized the law as follows:

> To support the conclusion that the claimed invention is directed to obvious subject matter, either the references must expressly or impliedly suggest the claimed invention or the Examiner must present a convincing line of reasoning as to why the artisan would have found the claimed invention to be obvious in light of the teachings of the references.

Nothing of that sort has happened in the case at bar. The final rejection must be removed.

To establish a prima facie case of obviousness, it is important that the prior art reference (or references when combined) must teach or suggest all the claim limitations. Finally, the teaching or suggestion to make the claimed modification and the reasonable expectation of success must be found in the prior art and not based upon Applicant's disclosure. In re Vaeck, 947 F.2d 488, 20 USPQ2d 1438 (Fed Cir. 1991). It is respectfully submitted that only after reading and understanding the Basford specification did the Examiner piece together two marginally relevant patents for his obviousness rejection. What the Examiner has done is use Applicant's own specification against himself to Applicant's great detriment. That is prohibited hindsight and is wholly unfair to the inventor Basford.

As noted by the inventor in paragraph 10 of his Declaration, his invention, if adopted Nationwide would cause enormous savings to the long haul trucking industry. For example, Basford reasoned as follows:

> [L]ong haul trucks consume over 16 Billion gallons of Diesel fuel per year in the U.S. Reducing the total aerodynamic drag of these trucks by about 15% will yield about 10% in fuel savings. If this invention achieves widespread use on long haul trucks, the potential fuel savings is well over one billion gallons per year, with corresponding air pollution savings. At current Diesel fuel prices of $2 per gallon, as of mid March 2003, the potential fuel cost savings is over $2 Billion per year for the trucking industry alone.

Claims 26 through 29 and 31 through 35 were rejected based upon an unfounded assertion that they are "indefinite" and that the claim language used "has failed to particularly point out and distinctly claim the subject matter which applicant regards as the invention." Not so.

In the specification, Mr. Basford carefully explained his invention and also explained the terms used to define the novel features of his invention. There is pending a Petition for Reconsideration under 37 CFR 1.181 relative to the 35 USC 112 rejection. That Petition will be supplemented by the Glossary of Terms submitted herewith. Suffice to say here that the rejection/objection by the Examiner is not well founded.

In his final rejection under 35 USC 112 the Examiner stated:

> Claim 26, lines 2 - 3, "a low pressure wake having an outer wake perimeter"; lines 8 - 10 "means positioning side by side vortex generators in a linear array ahead of the two side, top and bottom trailing edges of said bluff body for generating counter rotating stream-wise vortices; and lines 15 - 17 "rear edges on said boattail plates sized to intercept the separated shear surfaces of said fluid layer at the outer perimeter of the

low pressure wake thereby providing maximum fluid-dynamic base drag reduction for said body" fails to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

It is respectfully submitted that the problem may well be that the Examiner is simply unfamiliar with the technical terminology commonly used in the field of aerodynamic drag reduction. Applicant responded to the Examiner by amendment filed on July 25, 2003 and specifically inserted into claim 26 the exact reference numbers for appropriate elements of his inventive Figures, and explained their applicability to the claim language. Please see, for example, the discussion starting on the last paragraph of page 14, page 15, and the top of page 16 of that non-entered amendment.

Furthermore, in the "Remarks" section of that July amendment, reference was made to the applicable Figures 2 and 3 of the Wheeler reference. The Wheeler figures were inserted into claim 26 at the appropriate place in order to show exactly how the invention accomplished the novel result heretofore unappreciated by the art. Nevertheless, the Examiner remained steadfast in his refusal to consider Applicant's efforts. When an Applicant has done all possible in a sincere effort to lead and assist, the resulting failure by the Examiner to read or communicate must surely lead to Appeal.

Terms such as base drag, base surface, boundary layer, trailing edge, separated shear surface, and low pressure wake, all have specific meanings that are well recognized, clearly understood and commonly used by all artisans working in the field of aerodynamic drag reduction. These terms are fully defined in the specification and in the accompanying Glossary of Terms. Anyone of ordinary skill in this art reading the claims

at issue would immediately recognize the contribution to this art made by the present invention.

These facts notwithstanding, Mr. Patel consistently ignored Mr. Basford's first (and second Declaration as well) and failed even to acknowledge that such Declarations were submitted. Not only that, but Mr. Patel has missed the most pertinent art which Mr. Basford has cited and explained at length.

In clear contrast to Mair and the other art, Basford teaches moving the rearward edge of shortened boattail plates roughly 50% closer to the rear of the truck. Such a simple step -- by hindsight -- provides both novel and commercially viable savings. Basford's unique edge location (whether boattail plates or a trailing panel of withdrawn Figure 7 and generic claim 35) works to provide greater drag reduction than the prior art. The Basford structure thus satisfies several significant criteria for a patentable invention.

Mr. Basford discovered that vortex generators, ala the Wheeler disclosure, cause the separated shear surfaces (elements 26, above) to sharply swing inward just aft of the trailing edges 24 of the bluff body. Basford combines known linear vortex arrays with boattail plates having rear edges placed so as to intercept those separated shear surfaces at the outer perimeter of the inwardly-turned (and smaller) low pressure wake. The location and positioning of these rear edges is much closer to the base surface of the trailer body than Bilanin, or Switlik or any other known art teaches or suggests.

Combining vortex generators and boattail plates is novel over the art. With a truck body moving in air (Claim 27), maximum base drag reduction is achieved when the rear edges of the three shortened boattail

plates are positioned in a rearward direction at about 1/6th the width of the truck's rear surface. (Please see Claim 31 and generic claim 35 which set forth that novel dimensional relationship in varying terminology.)

The art relied upon by the Examiner is Switlik '059 in combination with Wheeler '837. What is lacking in such art is the precise combination of linear arrays of vortex generators in combination with boattail plates, as claimed. Moreover the critical rearward extension length of about 1/6 the width of the base surface (assuming width less than height, as usually is the case) is not suggested by such an art combination.

Inventor Basford defines the size of his shortened boattail plates so that the rear edges of such plates intercept the separated shear surfaces after those shear surfaces have passed over the vortex generators, with the rear edges of the boattail plates being located at the outer perimeter of the low pressure wake. This novel, and heretofore unknown combination, provides maximum fluid-dynamic base drag reduction for a bluff body. That novel combination constitutes the crux of the Basford invention. One wonders if these aerodynamic improvements can be presented in any clearer terminology. The claimed invention is presented in clear and concise terms, and is neither vague nor indefinite. Moreover, the invention is easily understood by anyone conversant with the basic aerodynamic terms.

In short summary, what has not been recognized before this novel invention, was that combining the two techniques - vortex generators and shortened boattail plates - would greatly improve base drag reduction provided that the extension length (ie. plate width, per se) of the boattail plates was about 1/6 of the width of the base surface.

Using the truck examples of the specification, the outside width of the rear base surface is about 102 inches, and the inventive 1/6 of 102 inches is about 18 inches. (It is 1/8th, or about 12 inches in Basford Fig. 9, in order to comply with the Department Of Transportation Regulations for trailers built after January, 1998). This Basford improvement is a far cry from the 40 to 56 inches of the prior art, including Bilanin at Column 9, lines 14 through 17, Switlik and the other references. The Basford invention is clearly novel over such art.

Note that this critical "1/6th the base width feature" (or "1/8th" in Basford Fig. 9) is clearly specified in some of the claims. The first Basford Declaration further sets forth ample reason why the prior art teaches away from this claimed distinction. In particular, the Basford Declaration confirms that independent Claims 26 and 35, for example, define a novel combination over all of the known and cited art.

As conceded by the Examiner, the Switlik reference is completely devoid of the Basford vortex generators for creating a smaller low pressure wake, which enables the separated shear surfaces to intercept the rear edges of the shortened boattail plates at a distance of only about 1/6 to 1/8 of the base surface width. Furthermore, nothing in Bilanin, Switlik or Wheeler suggests such a combination.

The Basford Declaration clearly explains these novel principles in carefully worded terminology defining a new and non-obvious solution to a problem which all prior artisans overlooked. If it were so readily obvious - as the Examiner contends - why is it not shown or suggested by the cited art? Instead, the cited art – Applicant respectfully submits - testifies to the worthiness, merit and novelty of the Basford invention. It clearly does not - as the Examiner contends - negate the claimed novelty.

worthiness, merit and novelty of the Basford invention. It clearly does not - as the Examiner contends - negate the claimed novelty.

Inventor Basford has described and claimed his invention in as clear and concise terms as possible. Moreover, consistent with the requirement for full disclosure, Basford provided detailed information on the most relevant prior art, and all the needed technical background information for an appreciation of this highly significant invention. Additionally Applicant paid all the required fees. In return, the Patent Office Examiner must make a good faith effort to fully understand and examine the application on its merits. That good faith evaluation simply was not done.

None of the references, singularly or in combination, supply guidance or suggestion for combining Wheeler with Switlik or Bilanin or, indeed, any other of the known art. In short it is respectfully submitted that the claimed invention is useful, novel and not obvious to persons with ordinary knowledge and skill in this technology.

The Examiner should be reversed, the rejection withdrawn, and all of the claims allowed.

Respectfully Submitted,

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I HEREBY CERTIFY THAT THIS CORRESPONDENCE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE AS EXPRESS MAIL ET791107051US POSTAGE PRE-PAID IN AN ENVELOPE ADDRESSED TO: COMMISSIONER FOR PATENTS, P.O. BOX 1450, ALEXANDRIA, VA 22313 - 1450 ON: January 26, 2004 (DEPOSIT DATE)

BY: Stanley R. Jones (REG. REP. REG. NO. 22,659.)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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PATENT & TRADEMARK OFFICE

In re Application of:	)	
	)	
Basford, William C.	)	Patent Examiner:
	)	Patel, Kiran B.
Filing Date: June 8, 2001	)	Art unit: 3612
	)	
Serial No.: 09/877,585	)	
	)	January 26, 2004
AERODYNAMIC COMBINATION FOR	)	Hallowell, Maine
IMPROVED BASE DRAG REDUCTION	)	Zip: 04347
--	)	

APPENDIX BOOKLET INDEX

Claims on Appeal .... (Tab 1)

Glossary of terms.. (Tab 2)

Switlik '059 & Wheeler '837.. (Tab 3)

Mair Paper .... (Tab 4)

Bilanin '808 .... (Tab 5)

CLAIMS ON APPEAL (26 - 29, 30, 31 - 35)

26. Apparatus for reducing the fluid-dynamic base drag of a bluff body moving through a fluid and creating, at the rear of the body, a low pressure wake having an outer wake perimeter, which bluff body has a substantially flat rear base surface, a pair of opposed side surfaces, and opposed top and bottom surfaces all joined with said rear base surface at side, top and bottom trailing edges, respectively, so as to form a box-like container, said apparatus comprising:

means positioning side-by-side vortex generators in a linear array ahead of the two side, top and bottom trailing edges of said bluff body for generating counter rotating stream-wise vortices in a fluid boundary layer passing generally along said bluff body and creating from said layer separated shear surfaces which turn sharply inward aft of said trailing edges;

four boattail plates inset and affixed a predetermined distance from the top and side trailing edges; and

rear edges on said boattail plates sized to intercept the separated shear surfaces of said fluid layer at the outer perimeter of the low pressure wake, thereby providing maximum fluid-dynamic base drag reduction for said body.

27. The apparatus in accordance with claim 26 wherein the bluff body is a land vehicle moving in air, which vehicle has only three boattail plates attached adjacent the top and opposed side trailing edges; and

three linear arrays of vortex generators, one array each associated with one each of said boattail plates.

28. The apparatus of claim 27 wherein the vortex generators are V shaped low drag vortex generators having an open end and a pointed end, and said apparatus further comprises:

said V shaped vortex generators in said linear arrays are positioned with said open end facing toward a forward end of said vehicle; and the pointed end of said V shaped vortex generators pointed toward the rear of said vehicle.

29. The apparatus of claim 27 wherein said vehicle includes a truck trailer body with a rear opening into said box-like container, and further comprising:

boattail plate hinging means allowing said plates to swing clear from said rear opening for said trailer body.

30. The apparatus of claim 27 wherein said trailer body has a pair of swinging rear doors vertically divided lengthwise top to bottom at about the center of the base surface, said method further comprising:

means dividing the top boattail plate at the point of division of the vehicle's rear swinging doors such that opening of the vehicle doors allows said boattail plates to separate and swing away together with the swinging doors of the trailer body.

31. Apparatus for reducing the fluid-dynamic base drag of a bluff body in accordance with claim 26, and further comprising:

means positioning said affixing means at a predetermined inset distance of about 8 to 9 percent of the lesser of the height or width of said rear base surface.

32. Apparatus for reducing the fluid-dynamic base drag of a bluff body in accordance with claim 26, said apparatus further comprising:

a front edge surface for each of said boattail plates; and

means hinging said front edge of said boattail plates to said base surface at said inset location.

33. Apparatus for reducing the fluid-dynamic base drag of a bluff body in accordance with claim 26 wherein said boundary layer has a given local thickness, said apparatus further comprising:

a thickness height for said generators in the range of 1/4 to 1/5 said local boundary layer thickness.

34. The apparatus of claim 26 wherein the cross sectional shape of the base surface of a bluff body has a perimeter shape other than a rectangle, and further comprising:

said boattail plates shaped with the perimeter of said base surface but at a smaller size, while maintaining the same predetermined inset distance from the edges of said bluff body and a similarly shaped rear edge for said boattail plates located to intercept the separated shear surfaces of said fluid flow at an outer perimeter of the low pressure wake.

35. Apparatus for reducing to a minimum the fluid-dynamic base drag of a bluff body moving through a fluid passing generally along said bluff body and creating, at the rear of the body, separated shear surfaces which define a low pressure wake having an outer wake perimeter, which bluff body has a substantially flat rear base surface with given height and width dimensions and a periphery of trailing edges, said apparatus comprising:

vortex generator means mounted adjacent to and forward of said trailing edges for generating counter-rotating stream-wise vortices in said fluid layer, which generators cause the separated shear surfaces to turned sharply inward thereby reducing the size of the low pressure wake, and

edge means coupled to said base surface and inset from said trailing edges for intercepting said separated shear surfaces at the outer perimeter of said low pressure wake, namely, at a distance behind said base surface of about 1/6th to 1/8th of said given height or width dimension, whichever is less.

Glossary of Terms
commonly used in connection with the
Aerodynamics of Land Vehicles

Compiled by the Applicant, January 2004, to support utility patent application 09/877,585, titled AERODYNAMIC COMBINATION FOR IMPROVED BASE DRAG REDUCTION, originally entitled "Apparatus to Reduce Base Drag behind Bluff Bodies"

Introduction

The subject application was written using the basic technical terminology commonly used and understood by all persons of ordinary skill in the art of subsonic aerodynamics in general, and the aerodynamic drag of highway vehicles in particular. Many of the standard terms used in connection with base drag at the rear of vehicles, were described in the specification under the heading "Background – Technical Information" on pages 2 through 5 of the original specification, and further described in connection with Fig. 1, which was provided to show graphically how base drag is created at the rear of a bluff body. Additional standard terminology associated with the prior art was described in the section titled "Background – Prior Art", on pages 6 through 17 of the original specification. This basic technical information was included in the specification to assist persons not completely familiar with the art field.

These basic technical terms were used in both the specification and the claims, in the interests of full disclosure, in order to make it easier for persons familiar with this art field, and conversant with it's standard terminology, to quickly, easily and completely understand the invention.

While the construction of the device or apparatus of the invention could conceivably be described without using any of the standard technical terminology of this art field, it was assumed that the technical terminology was helpful to fully describe how the invention works, i.e., how it reduces aerodynamic base drag.

The following glossary of technical terms has been assembled in a further effort to assist persons not fully familiar with this art field. The majority of terms in this glossary should be familiar to anyone who has taken a college level course in physics, fluid mechanics, or aerodynamics, in the past forty years, so there has been no attempt to report a specific source for all these terms. For the few newer terms coined within the past forty years, such as **boattail plates**, and **trailing panel**, the sources or origins of these newer terms were specifically reported in the specification, and these sources were included in the references provided to the USPTO in the IDS, and these sources are repeated again in this glossary through the use of footnotes.

Aerodynamics - that branch of fluid dynamics which deals with gasses, especially air, as opposed to liquids

afterbody - in aerodynamics, an **afterbody** is the rear end body shape of a moving body, which is typically covered by a low pressure wake, and is subject to a drag force due to the reduced pressure on the base surface.

backstep - in aerodynamics, a **backstep** is a sharp change in the side surfaces of a moving body, or a sharp change in the outside wall of a duct or channel containing a moving fluid, which causes the fluid boundary layer to separate from the surface and form a recirculation bubble or low pressure wake.

base area – The surface area on the rear of a moving body that is covered by fluid in the low pressure wake. For a simple box shaped truck body, the base area is the same as the **base surface** of the moving body.

base drag - **base drag** is a force resisting the motion of a bluff body, caused by the reduced fluid pressure (less than ambient pressure) against the rear or base surface of a bluff body. Some people visualize base drag as a suction force applied to the rear or base surface of a moving body.

base surface - In aerodynamics, the **base surface** is the rear or downstream surface of a bluff body, which is covered by the low pressure wake. For a simple box shaped truck body, the base surface is the flat rear surface of the truck body, which typically includes one or more large cargo doors and the surrounding door frame.

bluff body - in aerodynamics, a **bluff body** is any body moving through a fluid, where the form drag, sometimes also known as pressure drag, is greater than the skin friction drag, as opposed to a **streamlined body** where the form drag is less than the skin friction drag. All highway vehicles, including typical long haul trucks, are examples of bluff bodies.

boattail - in aerodynamics, the term **boattail** refers to a long rounded or tapered rear end or afterbody shape of a bluff body. A **full boattail** typically ends in a single point or an edge, while a **truncated boattail** is cut off at some point before the taper reaches a point or edge. **Boattails** have been well known in aerodynamics since at least the 1920s.

boattail plates – in aerodynamics, **boattail plates** are flat plates of a predetermined size, mounted generally perpendicular to the base surface of a box shaped truck body, as first disclosed in Bilanin '808, in 1987. They are called **boattail plates** because they produce much of the same aerodynamic effects and benefits of full boattails, without requiring the greater length and expensive curved or tapered construction of full boattails. The term **boattail plates** was used repeatedly in reference 17, a technical report by Lanser, et al, on the testing of these devices in the full scale wind tunnel at NASA Ames in the 1980s.

bottom surface - in aerodynamics, the bottom surface of a moving body is the surface which faces, or is closest to, the surface of the earth, or other relatively flat and stationary surface.

boundary layer - a thin layer of fluid at the surface of moving bodies which tends to stick to and is influenced by the motion of the body, because of the viscosity of the fluid. **Boundary layers** can be either laminar or turbulent, and were described by Prandtl in 1904

counter rotating streamwise vortices – **streamwise vortices** where any two adjacent vortices rotate in opposite directions so they reinforce each other rather than oppose or fight each other. Figs. 2 and 3 in Wheeler '837 show **counter rotating streamwise vortices** formed by his V shaped low drag vortex generators.

drag – in aerodynamics, **drag** is a force the opposes the motion of a body as it moves through a fluid.

fluid-dynamics – the scientific study of the forces and motions of fluids.

forebody – in aerodynamics, the **forebody** is the front end or front body shape of a bluff body. For a simple shoebox shape, the forebody is the flat front surface of the box.

form drag - in aerodynamics, **form drag** (also known as pressure drag) is the resistance force exerted on a moving body due to changes in the pressure of the surrounding fluid. The two components of form drag are **forebody drag** which is exerted on the front or forebody of a bluff body, and **base drag**, which is exerted on the rear or base area of a bluff body.

free stream air – in aerodynamics, the term **free stream air** refers to air that is far enough from a moving body so that the moving body has little or no effect on it.

friction drag – **friction drag**, also known as **skin friction drag**, is the resistance to motion which a moving body experiences due to the viscosity or internal friction of the fluid surrounding the moving body.

full boattail – a rounded or tapered rear body shape which typically terminates in a point or edge. To provide maximum base drag reduction, the length of a full boattail must typically be three to four times the height or width of the base surface of a bluff body.

full length boattail plates - full length boattail plates are **boattail plates** built with the preferred plate dimensions as disclosed in Bilanin '808, or more specifically, with a preferred length or rearward extension of 0.40 to 0.56 times the width of the base surface of the bluff body.

hydro-dynamics - that branch of fluid dynamics which deals with liquids, as opposed to gasses.

land vehicle - in aerodynamics, a **land vehicle** is a moving vehicle which moves on, or close to, the surface of the earth. Trucks and automobiles are common examples of land vehicles.

longitudinal centerline – in aerodynamics, the **longitudinal centerline** of a moving body is a centerline drawn through the body parallel to the direction of motion of the moving body.

low pressure wake - the space or volume of fluid immediately behind the rear or base surface of a bluff body where the fluid pressure is less than the atmospheric or ambient pressure. Fig. 1 in the specification shows how the low pressure wake and base drag are created.

recirculation bubble –in aerodynamics, a **recirculation bubble** (sometimes also called a separation bubble) is a mass or volume of air behind a backstep or other obstruction, with a generally circular internal flow pattern.

separation - in aerodynamics, **separation** is the phenomenon where fluid in a boundary layer separates from the surface of the body. The point or line of separation typically marks the leading edge of a recirculation bubble.

separated shear surface - in aerodynamics, a **separated shear surface** (sometimes also known as a **shear surface**, or **shear layer**, or **separated shear layer**, or **free shear layer**) is the boundary between a body of fast moving free stream air and a body of slower moving air, such as air in the low pressure wake behind a moving body. The relative speed difference between the two bodies of air results in turbulent mixing at this boundary, which pulls on or pumps away air from the slower moving body of air in the low pressure wake.

shortened boattail plates - The term "**shortened boattail plates**" as defined by the current Applicant in the specification, refers to boattail plates built with roughly half the preferred length or rearward extension of the boattail plates previously disclosed in Bilanin '808. In other words, shortened boattail plates will be roughly 1/6 the width or height of the base surface of a bluff body, whichever is less, as opposed to the **full length boattail plates** as disclosed by Bilanin '808, which must be at least twice as long, in order to provide maximum base drag reduction.

skin friction drag – the same as **friction drag**

streamlined body - in aerodynamics, a **streamlined body** is any moving body where the form drag or pressure drag is less than the skin friction drag. This typically also means that fluid in the boundary layer travels all the way from the front to the rear of the moving body without separating from the body.

streamwise vortex - a **streamwise vortex** (also known as a **trailing vortex**) is a vortex rotating about an axis which parallels the direction of flow in a fluid stream passing a moving body, as opposed to a **standing vortex** which rotates about an axis generally perpendicular to the direction of fluid flow past a moving body. Figs. 1 through 3 in Wheeler '837 show streamwise vortices formed by his V shaped low drag vortex generators, while Fig. 2B in Bilanin '808 shows standing vortices that form behind the trailing edges of a truck body.

trailing - in fluid dynamics, including both aerodynamics and hydrodynamics, the term trailing generally means downstream or rearmost.

trailing edges - in aerodynamics, **trailing edges** are the rear or downstream edges of a bluff body where fluid in the passing boundary layer separates from the bluff body. For a simple box shaped bluff body such as a typical truck body, the trailing edges are the rear edges of the truck body.

trailing panel - in aerodynamics, a **trailing panel** is a flat panel mounted behind and parallel to the base surface of a bluff body, to reduce the base drag of the bluff body. A trailing panel for use behind truck bodies was disclosed in Baker '366.

trailing vortex – a **trailing vortex** (also known as a **streamwise vortex**) is a vortex rotating about an axis which parallels the direction of flow in a fluid passing a moving body, as opposed to a **standing vortex** which rotates about an axis perpendicular to the direction of fluid flow past a moving body. Figs. 1 through 3 in Wheeler '837 show trailing vortices formed by his V shaped low drag vortex generators, while Fig. 2B in Bilanin '808 shows standing vortices that form behind the trailing edges of a truck body. The term **trailing vortex** also implies a **streamwise vortex** that extends beyond the trailing edges of a body.

truncated boattail – a truncated boattail is a boattail that is cut off or truncated before it reaches a point or edge. Truncated boattails are typically cut off at a point just ahead of where the boundary layer would otherwise separate from the surface of the boattail. Truncated boattails can be much shorter than full boattails but they provide less base drag reduction.

underride bars – **underride bars** is the common term used in the trucking industry to designate the crash guards mounted at the rear end of large trucks to prevent automobiles and other low vehicles from passing under the truck body in a rear end collision. Typical underride bars are shown in Fig. 2 of the specification.

V shaped low drag vortex generators - Vortex generators built and used as disclosed in Wheeler '837.

vortex - in aerodynamics, a **vortex** is a body of air which rotates about a central axis

vortex generator - in aerodynamics, a **vortex generator** is any device or apparatus that generates one or more trailing vortices in the passing fluid

vortices - the plural of **vortex**

DRAG–REDUCING TECHNIQUES FOR AXI–SYMMETRIC BLUFF BODIES

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ABSTRACT

The numerous experiments that have been made on drag-reducing devices for *two-dimensional* bluff bodies have been used as a guide to indicate promising lines of investigation for axi-symmetric bodies. For the latter case, experiments on splitter plates, cylindrical extensions, base bleed and ventilated cavities are reviewed. Of these devices, base bleed is the only one that gives any useful reduction of drag. Unfortunately base bleed cannot be effectively applied to road vehicles. The air flow rate available on a typical vehicle from its ventilation system is too small to give any significant effect. If a special air supply giving a larger air flow were to be provided, the intake momentum drag would be more than enough to counteract any drag reduction due to base bleed.

For a blunt-based axi-symmetric body, a boat-tailed afterbody is much more effective in reducing zero-yaw drag than any other device that has been tried. Furthermore, experiments have shown that as the yaw angle of a boat-tailed body is increased from zero, the axial force can decrease slightly up to a yaw angle of about 10 or 15 degrees, although at larger yaw angles it becomes much greater.

The mode of action of a boat-tailed afterbody is explained, and some of the factors leading to a good design are discussed. The possibility of using boundary-layer control in conjunction with a boat-tailed afterbody is considered briefly.

NOTATION

A	Base Area
A_0	Porous area of base (with base bleed)

References pp. 178-179.

b	Width of cruciform splitter plate on a cone (see Fig. 1).
C_D	Drag coefficient referred to maximum cross-sectional area.
ΔC_D	Reduction of drag coefficient.
C_p	Pressure coefficient.
C_{pb}	Base-pressure coefficient.
C_q	Bleed-flow coefficient, $\equiv Q/UA$
C_x	Axial-force coefficient referred to maximum cross-sectional area.
d	Maximum diameter of body of revolution.
d_B	Base height (two-dimensional) or base diameter (axi-symmetric).
d_s	Diameter of a sting-like cylindrical extension.
f	Drag-reduction factor, $\equiv \Delta C_D/0.165$
k	Resistance coefficient at bleed-air outlet.
ℓ	Length of boat-tailed afterbody.
n	Number of air changes per hour, for ventilation.
Q	Volume flow rate of base bleed.
R	Maximum radius of boat-tailed afterbody.
r	Local radius of boat-tailed afterbody.
t	Maximum thickness of two-dimensional aerofoil.
U	Stream velocity.
U_o	Average bleed velocity.
V	Internal volume of vehicle.
X_r	Distance from base to re-attachment on sting or to mean position of bubble closure.
x	Distance downstream from section A in Fig. 5.
β	Boat-tail angle (Fig. 5.)
δ	Boundary layer thickness.
ν	Kinematic viscosity of air.
ρ	Density of air.

INTRODUCTION

Because of the difficulty of theoretical analysis, the study of drag-reducing techniques for bluff bodies has been almost entirely experimental. The bodies that have been studied have usually been two-dimensional, and sometimes axi-symmetric, and much less work has been done on more complex three-dimensional bodies. It is for this reason that attention is concentrated in this paper on axi-symmetric bodies, rather than on general 3-D shapes.

A two-dimensional bluff body in a stream at a low Mach number generates a wake in the form of a Karman street, a regular array of vortices with circulation of alternate sign. This vortex wake is known to be associated with a large drag force on the body, and any device (such as a splitter plate placed in the near-wake) that causes the vortices to form further away from the body gives a reduction of drag.

Some three-dimensional bodies generate wakes in which there is noticeable periodicity, indicating some regular pattern of vortex shedding, but for axi-symmetric bodies any regular vortex shedding is only a minor feature of the flow. Correspondingly, the drag coefficients of axi-symmetric bluff bodies, based on their frontal areas, are usually considerably smaller than those of the related two-dimensional bodies. For example, at a Reynolds number of 10^6 the drag coefficient of a long circular cylinder with its axis normal to the stream is about 0.35, whereas that of a sphere is only about 0.1.

These results lead to two important points. First, a drag-reducing device that is effective on a two-dimensional body because of its action in suppressing or delaying the formation of the vortex street is not likely to be effective on an axi-symmetric body. Second, the maximum reduction of drag coefficient that can be obtained by the use of a device is likely to be less for an axi-symmetric body than for a two-dimensional one, because the drag coefficient without any device present is already lower for the axi-symmetric body.

Nevertheless, since extensive experiments have been made on drag-reducing devices for two-dimensional bodies, it may be profitable to examine whether the results of these experiments suggest any useful forms of drag-reducing devices for axi-symmetric bodies.

The following drag-reducing devices have been found to be effective on *two-dimensional* bodies.

Splitter Plates – Roshko (1954), Bearman (1965), and others have shown that a splitter plate with a length equal to only one base height can in some cases reduce base drag by as much as 50%. One important effect of such a splitter plate is to move the start of the vortex street downstream and away from the base. With a longer splitter plate, the vortex street is suppressed entirely and the base drag may be reduced by 60% or more.

References pp. 178-179.

Base Bleed – Bearman (1967) has shown that outward flow of air from a blunt base can reduce the base drag by as much as 67%. This "bleed" has an effect similar to that of a splitter plate, in that it displaces the start of the vortex street downstream and eventually, at sufficiently large bleed rates, suppresses the vortex street entirely. Bearman has shown that the relationship between vortex-formation position and base pressure is the same with base bleed as with a splitter plate.

Generally, base bleed is most effective in reducing drag when it is distributed over a large proportion of the base area, but Poisson-Quinton & Jousserandot (1957) have shown that a thin plane jet on the centre line can reduce base drag by acting as an "aerodynamic splitter plate".

Ventilated Cavities – Experiments by Nash, Quincey & Callinan (1966) have shown that a thin-walled cavity, with a depth equal to one base height, reduced the base drag of a blunt-based two-dimensional aerofoil at zero incidence by about 23%. When the cavity was "ventilated", by cutting slots in the thin walls at the top and bottom, the reduction of base drag was as much as 60%. Nash *et al.* suggest that the cavity (without ventilation) increases the stability of the wake close behind the body and hence reduces the strength of the vortices in the street. When the cavity is ventilated, there probably is a flow of air from the external stream through the slots into the cavity, and this may have an effect rather like base bleed.

Trailing-Edge Notches – Tanner (1972) has shown, that the drag of a blunt-based aerofoil at zero incidence may be greatly reduced by some form of notched trailing edge. The best arrangement of notches reduced the base drag by 64%. It seems likely that the notches cause the formation of streamwise vortices, and that these prevent the formation of an orderly two-dimensional vortex street.

Boat-Tailing – Experiments on two-dimensional aerofoils with boat-tailed afterbodies and blunt bases have been made by Maull & Hoole (1967). The basic aerofoil, of maximum thickness t, consisted of a semi-elliptical nose of length 3t followed by a parallel portion, also of length 3t. Various boat-tailed afterbodies were added to this basic aerofoil and the pressure drags of these afterbodies (including base drag) were compared with the base drag of the basic aerofoil. The reduction of drag that is obtained depends on the extent of the boat-tailing; in the extreme case of boat-tailing the base height falls to zero and the aerofoil has a sharp trailing edge. When the ratio of base height d_B to maximum thickness t was 0.75, the afterbody drag was reduced by more than 40%, while with $d_B/t = 0.5$ the reduction was 75%.

Of the devices that have been listed here, the trailing-edge notches do not appear to have any useful analogue in the axi-symmetric case. There is also difficulty in conceiving a useful axi-symmetric analogue of a two-dimensional splitter plate, but some attempts have been made to reduce the drag of axi-symmetric bodies by adding extensions at the base, and these will now be considered. Axi-symmetric forms of the

other devices that have been mentioned will also be discussed.

BASE EXTENSIONS

In attempts to find axi-symmetric analogues of two-dimensional splitter plates, two different forms of base extensions have been tried on axi-symmetric bodies..

Tanner (1965) attached long cruciform splitter plates, as shown in Fig. 1, to the bases of a series of cones having total included apex angles from 15° to 120°. The base diameter of the cone was 80mm for the 15° apex angle and 98mm for all the others. The cruciform plates were 2mm thick and 250mm long, and their forward edges were 10mm behind the base of the cone. The plates were supported on a central tube of 30mm outside diameter. For the measurements without splitter plates, the cones were supported on a long sting of 25mm diameter. Fig. 1 shows the increase of base-pressure coefficient, ΔC_{pb}, as a function of cone apex angle and b/d, for a Reynolds number Ud/ν of about 2×10^5. There is an appreciable reduction of base drag for the larger apex angles, but the reduction becomes very small as the cone angle approaches zero. At each angle the maximum effect occurs near b/d of unity.

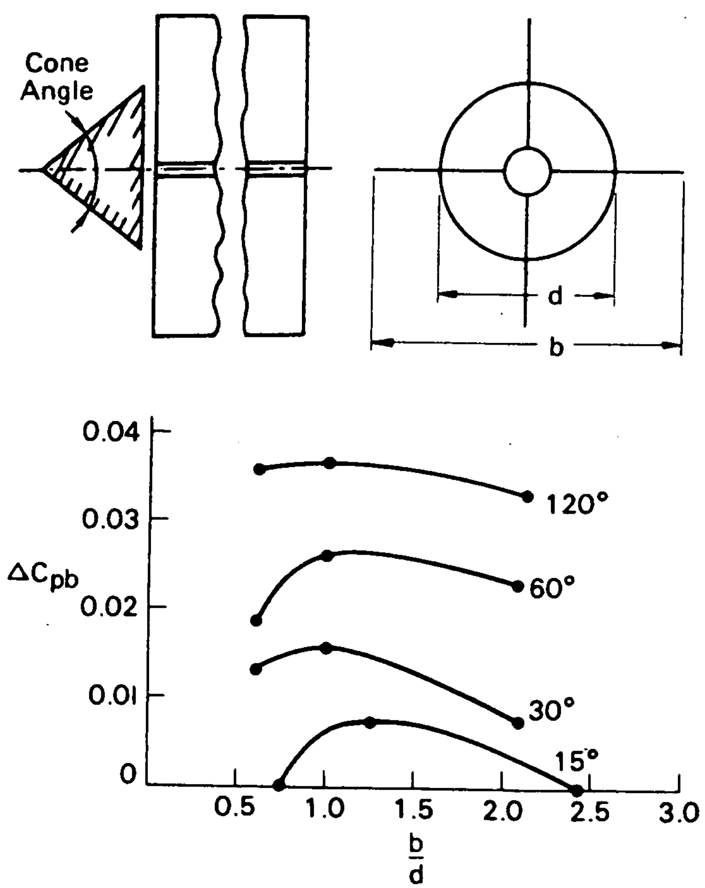

Fig. 1. Increase of base-pressure coefficient due to cruciform splitter plates attached to bases of cones. Total apex angles of cones are marked on curves (Tanner, 1965).

References pp. 178-179.

Calvert (1967) made experiments to determine the effect of long, central, cylindrical extensions of different diameters; they were of the form used as support stings. He remarked that the geometrical axi-symmetric analogue of a thin two-dimensional splitter plate would be a thin central spike; this would not be expected to have any appreciable effect, but cylindrical extensions of various diameters might give results of interest. The basic body consisted of a cylinder of diameter d and length 3.08 d, with a blunt base and a semi-ellipsoidal nose of length 1.33d. The added stings were rather long (8 base diameters), and the ratio of their diameter to the base diameter varied from $d_s/d = 0.17$ to 0.83. The Reynolds number Ud/ν was between 3×10^4 and 9×10^4. Measurements were made of base-pressure coefficient C_{pb} near the outer edge of the base, and of the distance X_r from the base to the re-attachment point on the sting or (for the model with no sting) to the mean position of bubble closure.

Fig. 2 shows that an extension of quite small diameter gives a substantial increase of base pressure, and a slight lengthening of the separation bubble. When d_s/d is about 0.33, the maximum base pressure is obtained; further increase of d_s/d gives a slight reduction of base pressure and a large reduction of bubble length. Although these results show a useful reduction of base drag for $d_s/d \approx 0.3$, it should be noted that all the extensions used were long. It seems likely that an extension with a length less than X_r would have little effect, and it is difficult to see any useful application of the results to drag-reducing devices for road vehicles.

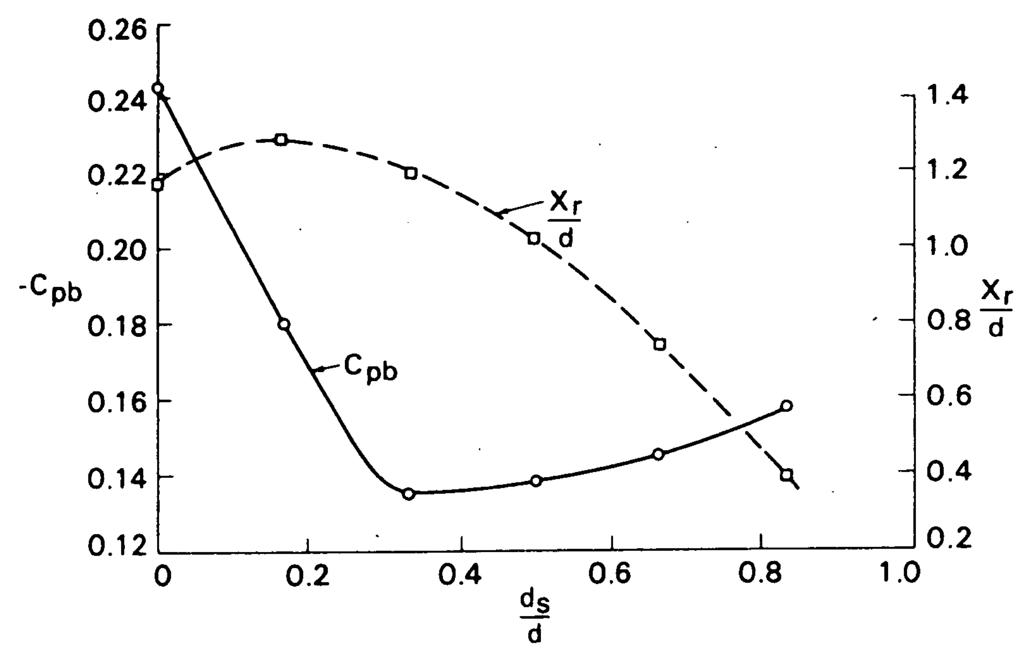

Fig. 2. Base-pressure coefficient and distance from base to reattachment for cylindrical body of diameter d with long sting-like cylindrical extension of diameter d_s (Calvert, 1967).

BASE BLEED

Calvert (1967) investigated the effect of base bleed on a cone with a total apex angle of 60° and a base diameter d of 76.2 mm. The uniformly porous base was made of Vyon sintered polythene, 1.6 mm thick, and the bleed air was pumped into the cone through a long tube, of outside diameter 9.5 mm, extending axially downstream from the centre of the base. The maximum porous area A_o was 3323 mm^2, representing 72.9% of the total base area A. The porous area was reduced progressively by blocking the surface in successive rings from the outside inwards, the minimum value of A_o being 0.283A. The Reynolds number Ud/ν was 6.1×10^4.

Fig. 3 shows the base-pressure coefficient C_{pb} plotted against a bleed-flow coefficient $C_q = Q/UA$, where Q is the volume flow rate of bleed air. As in the two-dimensional case, at a fixed bleed rate the best drag reduction is obtained with a large porous area, giving a low velocity of ejection; however, in the axi-symmetric case the reduction of drag is much smaller. At a given C_q, smaller porous areas increase drag, except at very small flow rates; this is probably caused by entrainment of air from the external stream into the jet of relatively high velocity from the porous base. This increases the curvature of the streamlines leaving the conical surface at the base, and so reduces the base pressure.

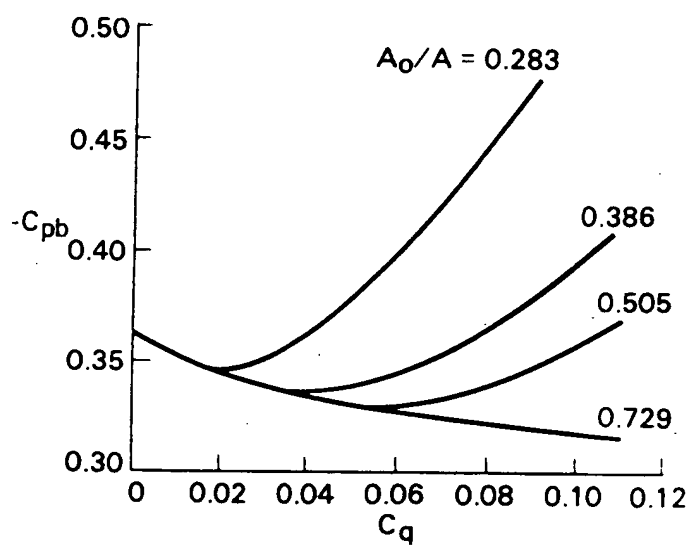

Fig. 3 Base-pressure coefficient on cone of 60° total apex angle with base bleed (Calvert, 1967).

Experiments by Sykes (1969), on a cylindrical body with an ogival nose, have shown a much greater reduction of drag with base bleed. The body diameter d was 100 mm, the length of the cylindrical portion was 5.15 d and the overall length was 6.27 d. The Reynolds number Ud/ν was 1.8×10^5. The bleed air was introduced into the body through a branch pipe of streamline section 0.25 d thick, which entered at the

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side. Although this conduit was about 4 d ahead of the base, it could have had some effect on the flow in the base region.

The results obtained are shown in Fig. 4, where the full lines show base pressures with bleed through an open central hole in a thin-plate covering the base (i.e. through an orifice), while the broken lines shown results obtained with the central hole covered with porous plastic sheet.

The results shown in Fig. 4 are qualitatively similar to those of Fig. 3. Again, the best drag reduction is obtained with a large value of A_0/A, and at this large value the introduction of the porous plastic sheet is beneficial.

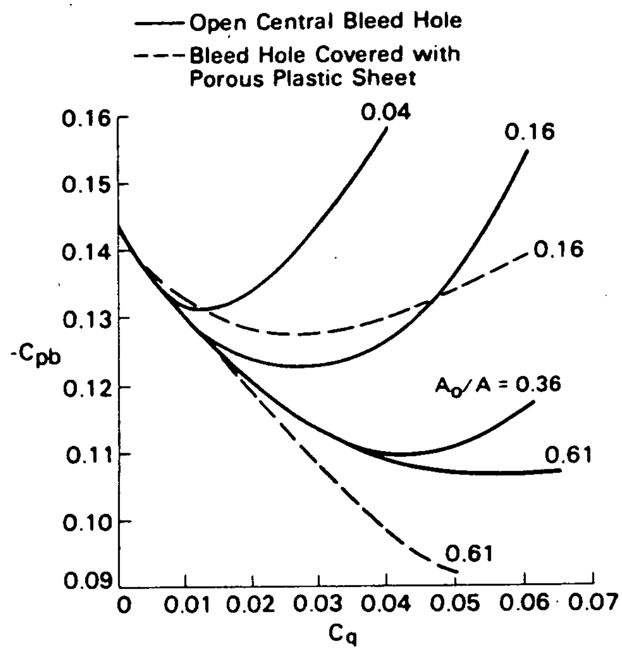

Fig. 4. Base-pressure coefficient on cylindrical body with ogival nose and base bleed (Sykes, 1969).

The effect of the porous plastic sheet in the results of Fig. 4 is difficult to explain. In the absence of this sheet the flow through the bleed orifice would be in the form of a contracting jet, perhaps with some asymmetry caused by the inlet pipe mentioned earlier. Introduction of the porous plastic sheet would tend to eliminate the contraction of the jet, so that its velocity would be lower for a given volume flow rate. This could explain the difference between the two curves in Fig. 4 for $A_0/A = 0.61$, but the difference in opposite sense for $A_0/A = 0.16$ and $C_q < 0.05$ cannot be explained in this way.

To estimate the overall value of base bleed as a drag-reducing device, it is necessary to consider also the intake momentum drag and the power required to pump the

bleed air through the outlet resistance. If the pressure drop at the outlet resistance is $\frac{1}{2}\rho U_o^2 k$, where U_o is the average bleed velocity over the area A_o, the ratio of ideal pump power to the power saved by drag reduction is

$$\frac{k\,C_q^{\,3}}{(A_o/A)^2\,\Delta C_{pb}}$$

where ΔC_{pb} is the increase of base-pressure coefficient due to base bleed. For the values suggested by Fig. 4. this is of order $2k \times 10^{-3}$, and the required pump power is therefore likely to be negligible.

The intake momentum drag is the drag caused by taking in air at the stream velocity U and ejecting it at the bleed velocity U_o. For a volume flow rate Q this is

$$\rho Q(U - U_o) = \rho A U^2 C_q \left(1 - \frac{U_o}{U}\right) .$$

The drag saved by base bleed is $1/2\ \rho A U^2 \Delta C_{pb}$. Hence, the ratio of intake momentum drag to drag saved by base bleed is

$$\frac{2C_q}{\Delta C_{pb}}\left(1 - \frac{U_o}{U}\right) \approx \frac{2C_q}{\Delta C_{pb}}$$

(since $U_o/U = AC_q/A_o$ and is small compared with one). Fig. 4 shows that $2C_q/\Delta C_{pb}$ is likely to be greater than 1, which means that the intake momentum drag is more than enough to counteract the saving of drag due to base bleed. Hence, the only way in which base bleed might be of value in reducing the drag of a vehicle is if the bleed air is taken into the vehicle for another purpose, such as ventilation.

For the purpose of ventilation, the air inside a vehicle of volume V may be required to be changed n times per hour. Then, if all the outlet air from the ventilation system is used for base bleed, $C_q = nV/AU$. For a typical passenger car, with V/A of about 3 metres and traveling at 100 km/h, this yields $C_q \approx 3n \times 10^{-5}$. The value of n required for ventilation is not likely to be greater than 25, so that C_q will only be about 0.00075, too small to have any appreciable effect on drag.

For a commercial truck, V has to be taken as the internal volume of the driver's cab, for that is normally the only space requiring ventilation. The ration V/A will therefore be less than for the passenger car, and again there is no useful reduction of drag to be obtained from using the ventilation outflow for base bleed.

It can be concluded that base bleed shows no promise as a means of reducing the drag of a road vehicle. This is primarily because of the large intake momentum drag, but the need to eject the air over a large proportion of the base area would also

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introduce severe practical difficulties.

VENTILATED CAVITIES.

It has already been mentioned that a cavity at the rear of a blunt-based two-dimensional aerofoil can give a large reduction of drag, especially when the cavity is ventilated by cutting slits in the walls. In contrast, some measurements by Goodyer (1966) showed that a cavity at the base of a body of revolution had no effect on drag when it was not ventilated, while the addition of ventilating slits gave a substantial *increase* of drag. These general results were not Reynolds-number sensitive, as was shown by repeating the experiments with boundary-layer transition fixed at various different positions along the body. The measurements were made on a cylindrical body with an ogival nose and overall length 11.3 d, suspended magnetically in a wind tunnel so that there was no support interference.

In selecting a depth for his cavity Goodyer was guided by the two-dimensional results of Nash, Quincey & Callinan (1966), and chose a depth approximately equal to one body diameter. He made no measurements with cavities of other depths, and it is possible that such cavities would have given different results.

BOAT-TAILING

It has been known for many years that the drag of a blunt-based body of revolution can be reduced significantly by boat-tailing the rear end in the manner shown in Fig. 5. This sketch refers to a basic body shape consisting of a long cylinder with a rounded nose, terminating in a blunt base at section A. The portion AB is a typical boat-tailed afterbody, terminating in a blunt base at B with a smaller area than that of the basic body at A. The addition of a further conical body BC, with semi-apex angle β chosen to match the shape of the boat-tailed afterbody at B, would give the "streamline" tail-piece ABC. Starting with this streamline shape there is, of course, a choice of position for the plane B defining the base of the boat-tailed afterbody. The value of the angle β, defining the slope of the boat-tailed afterbody at its base B, is obviously one very important variable. If this angle is too large the boundary layer separates before reaching B, while if it is too small the afterbody is unnecessarily long for a given diameter ratio d_B/d, where d is the diameter at A

Many of the experiments that have been made on boat-tailed afterbodies have not been relevant to the drag of land vehicles because they have been made at high Mach numbers, often greater than 1. Even when measurements at lower speeds have been included, the lowest Mach number has often been as high as 0.6, so that compressibility may still have had some effect.

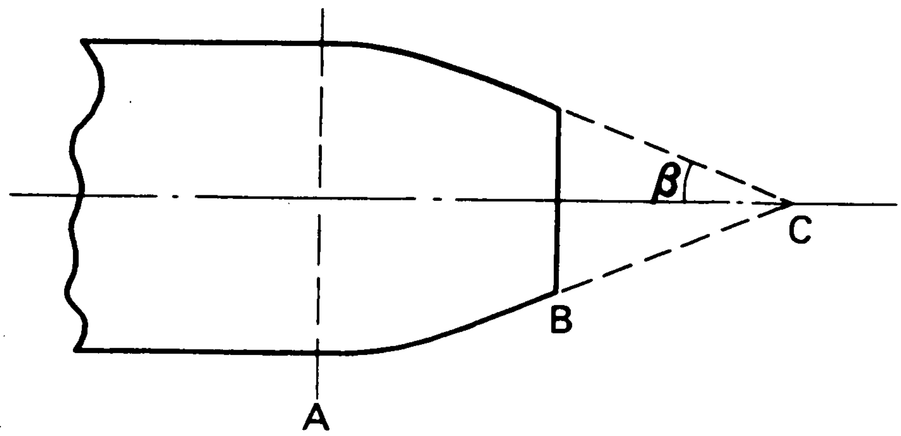

Fig. 5. Boat-tailed afterbody (Mair, 1969).

An undesirable feature of some of the earlier work was a tendency to concentrate too much on base drag, and to pay too little attention to the equally important drag force acting on the curved surface AB (in Fig. 5). There was also a tendency to concentrate on circular-arc or straight conical profiles, the latter often having no rounding at the section A so that there was a discontinuity of slope there. In some of the more recent work, the experiments have been made with one or more jets issuing from the base B, and a single jet has sometimes been simulated by a long cylinder extending downstream from the base, as in the work by Reubush & Putnam (1976). Consideration of the drag component obtained by integration of the measured pressure distribution on the curved surface AB shows that this pressure distribution is seriously affected by the real or simulated jet downstream of B, so that the results are not applicable to a boat-tailed afterbody without a jet.

In some experiments by Mair (1969) at a Mach number of 0.13, attention was concentrated on the form of boat-tailed afterbody that would give the greatest possible reduction of drag. The basic body consisted of a cylindrical portion of diameter d and length 3 d, with a semi-ellipsoidal nose of length 1.3 d. The Reynolds number Ud/ν was 0.46×10^6. A transition wire on the nose ensured that the boundary layer on the cylindrical portion was turbulent, the total thickness δ at the base being about 0.066 d. Some measurements were also made with the boundary layer artifically thickened to give $\delta = 0.2$ d at the base, but the results obtained were little different so all the results given here refer to the thinner boundary layer.

Inviscid flow calculations for the body with various forms of streamline tail attached showed that the pressure coefficient C_p had a nearly constant value of about -0.04 over a length of about one d near the middle of the cylindrical portion. This is only about one-tenth of the value found at the peak suction position on a typical streamline tail just behind A, indicating that the body was effectively "long", so that the pressure distributions at the nose and tail were nearly independent of one

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another. For such a long body, in inviscid flow, the pressure drag of the nose and of the tail would each be zero.

The measured base-pressure coefficient at A on the basic body was -0.165. Thus an "ideal" afterbody, with zero skin friction and with pressure distribution as for inviscid flow, would give a reduction of drag coefficient $\Delta C_D = 0.165$.

The actual experimental values of ΔC_D found for the various afterbodies may be compared with this ideal value by introducing a drag reduction factor $f = \Delta C_D/0.165$. It should be noted that, in a real fluid, f may be considerably less than one even for a conventional streamline tail tapering to a point; for such a tail, early work by Lock & Johansen (1933) found the value of f to be 0.72.

The best boat-tailed afterbody, found in this series of measurements (Mair, 1969) was the one that is drawn to scale in Fig. 5. This is a cone with $\beta = 22°$, joined by a curved fairing of length 0.5 d to the cylindrical body at A. Values of the drag reduction factor f are shown in Fig. 6 for this afterbody, as a function of the length ℓ from the original body-base A to the boat-tail cut-off plane B. The position shown for B in Fig. 5 corresponds to $\ell/d = 0.76$, for which f = 0.74. This is actually better than the value found for the streamline tail mentioned earlier, and even with $\ell/d = 0.6$ the value of f is 0.68, not much less than for the streamline tail.

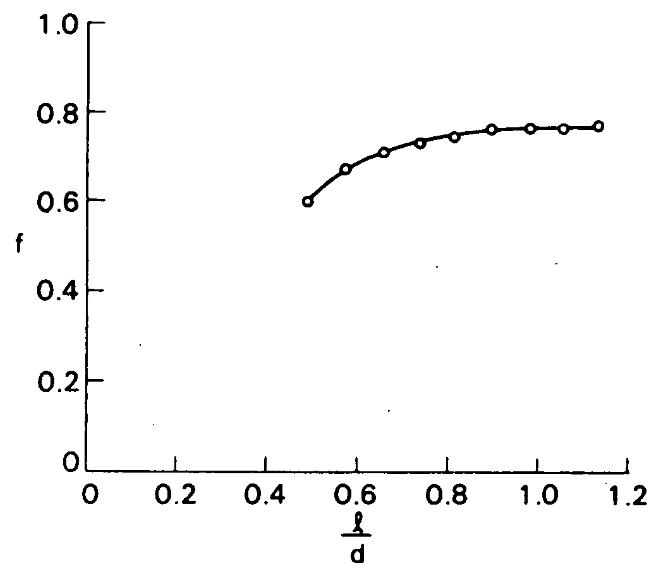

Fig. 6. Variation of drag reduction factor f with length ℓ of afterbody for boat-tailed afterbody shown in Fig. 5, $\beta = 22°$ (Mair, 1969).

For this particular afterbody with $\ell/d = 0.76$ (and for some other related ones) measurements of pressure distribution have been made by Bostock (1972) on a long yawed body at the same Reynolds number. The length of the body was 14 d or greater, and its upstream end was attached to a hinge on the wall of the wind tunnel. This arrangement, which had the body nose very near the wall, did not allow studies of the model at small or zero yaw angles. However, for the angles of yaw considered

($\geq 10°$) the flow at the tail was not affected by the upstream hinge or by the total body length, provided the latter was greater than about 10 d.

Bostock integrated the measured pressure distributions to obtain axial-force coefficients C_x based on the maximum cross-sectional area. Since the earlier measurements by the present author had shown that increase of boundary-layer thickness made little difference to either the drag or the pressure distribution on the boat-tail, the difference of body length between the two sets of measurements is not likely to have a serious effect on the comparisons.

The axial-force coefficient at zero yaw, which could not be obtained by Bostock, was extracted from the data of Mair (1969). First, for the body at zero yaw, boundary layer calculations by the method of Head (1960), using the measured pressure distribution, have shown that the contribution of skin friction to the drag coefficient of the afterbody is about 0.008 for $\ell/d = 0.76$. For comparison with Bostock's axial-force coefficients C_x for the yawed body (which do not include skin friction) this amount should be subtracted from the measured afterbody drag coefficient at zero yaw. Since Fig. 6 gives $f = 0.74$ for $\ell/d = 0.76$, the value of C_x for zero yaw is $0.165\,(1 - 0.74) - 0.008 = 0.035$. This value, together with those found by Bostock at yaw angles up to 30°, is plotted in Fig. 7. The same diagram also shows results for a boat-tailed afterbody of the same length and the same general form, but with $\beta = 26°$.

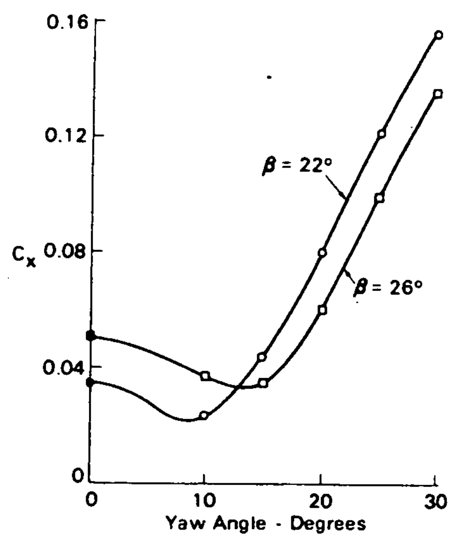

Fig. 7. Axial-force coefficients on boat-tailed afterbodies with $\ell/d = 0.76$ (skin friction not included). Open symbols Bostock (1972), closed symbols Mair (1969).

The striking feature of Fig. 7 is the *reduction* of C_x that occurs with both afterbodies as the yaw angle is increased from zero to about 10° or more. There is good evidence that this trend is genuine and is not due to a spurious comparison

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between two sets of measurements made under conditions that were not identical. For example, the Bostock points for $\beta = 26°$ and yaw angles of 10° and 15° indicate a definite minimum in that region. Similar but rather weaker evidence at these same yaw angles was found for $\beta = 30°$, although C_x was then higher than for $\beta = 26°$ at all yaw angles up to 25°.

FURTHER DISCUSSION OF BOAT-TAILED AFTERBODIES

Because boat-tailed afterbodies are so effective in reducing drag, it may be useful to consider their mode of action in more detail.

Fig. 8 shows the pressure distribution on the afterbody shown in Fig. 5, with $\beta = 22°$, for two different lengths ℓ. The distance x is measured downstream from the section A in Fig. 5. The point C in Fig. 5 is at $x/d = 1.50$, so that the pressure distribution on the complete body with pointed tail may be expected to be almost the same as that shown in Fig. 8 for $\ell/d = 1.37$. The other curve shown in Fig. 8, for $\ell/d = 0.67$, shows that when the body is cut off by a plane such as B in Fig. 5, there is little effect on the pressure distribution upstream of B. Because most of the pressure recovery on the longer body occurs in the range of x/d less than about 0.7, little is to be gained by making the cutoff at x/d larger than that. The cut-off body has in addition a lower skin-friction drag, while the penalty for the lower base pressure, caused by the lost pressure recovery on the cut-off piece, is small as it acts only on a relatively small base area.

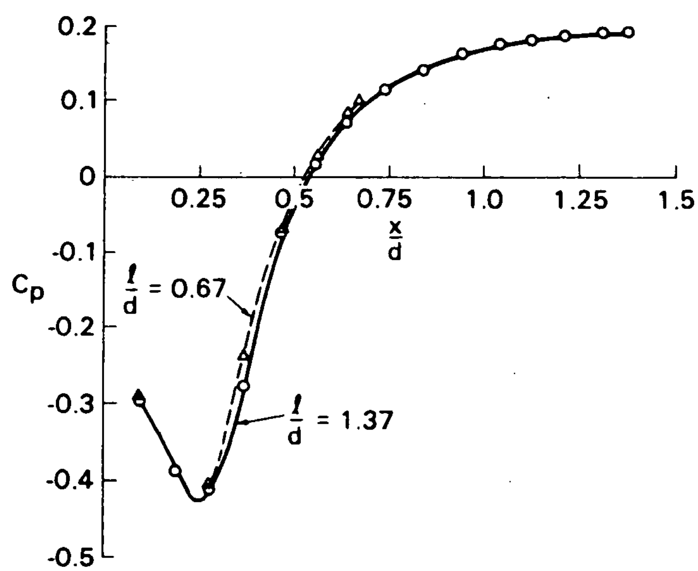

Fig. 8. Pressure distribution on boat-tailed afterbody with $\beta = 22°$ (Mair, 1969).

These results suggest a possible approach to the problem of predicting the drag of a

boat-tailed afterbody with a blunt base. The pressure distribution could be calculated for the complete afterbody with a pointed tail, with allowance for the boundary layer displacement effect, and it might be assumed that for an afterbody cut off at $x = \ell$ the pressure distribution for $x < \ell$ would be the same as for the complete body. Unfortunately, calculations of drag made on this basis, using experimental pressure distributions for various afterbody lengths, have shown that no useful estimates of drag can be obtained.

The reason for this disappointing result can be seen by reference to Fig. 9 which shows the total drag and its three components for the boat-tailed afterbody with $\beta = 22°$. Curve A represents the measured total drag, B is the measured base drag, and C is the calculated skin-friction drag. The remaining component, the pressure drag on the curved afterbody, was obtained as the differential D = A-B-C. In the range of ℓ/d that is of most interest, from about 0.6 to 0.8, the positive drag component D due to low average pressure on the curved surface of the afterbody is substantially offset by the base drag B, which is negative in that region. Further, seemingly small changes of pressure distribution can have, when integrated, a substantial effect on the component D. Since, after addition of the negative base drag B, the proportional effect on the total drag A is even greater, the suggested method of calculating drag is of no practical value.

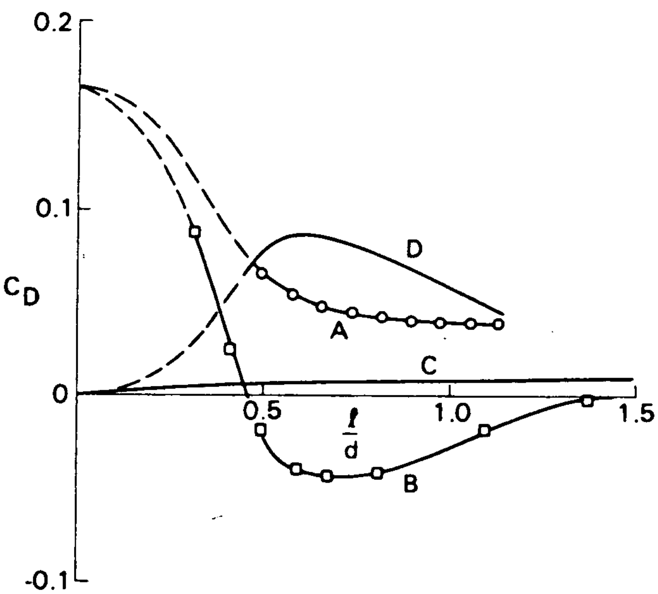

Fig. 9. Components of drag coefficient for boat-tailed afterbody with $\beta = 22°$ (Mair, 1969). A, measured total drag; B, measured base drag; C, calculated skin-friction drag; D, afterbody drag, excluding base, calculated as A-B-C. - - - possible extrapolation to zero length.

The requirements for the design of a good axi-symmetric boat-tailed afterbody may now be considered. First, it is clear that the boundary layer should not separate

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upstream of the base. If separation occurs at some station S, upstream of the base B, there will be little change of pressure between S and B so that the body can be cut off at S without much effect on the drag. The body that is cut off at S will have separation at the base, and, being shorter, will be a better practical design than the original body cut off at B.

For discussion of the other design requirements it is useful to refer to Fig. 10, which shows C_p (r/R) plotted against r/R for a streamline afterbody on a long cylindrical body, as calculated for inviscid flow. For this case the net drag is zero, so that the areas of the two loops A and B are equal. Now suppose that this body is cut off to form a blunt base, say at the section where r/R = 0.72, represented by the point P in Fig. 10. The pressure distribution upstream of P will be nearly the same as for the complete body and the pressure on the base will be the same as at P, so that the pressure drag of the cut-off body will be proportional to the area of the part of the loop A that is above the straight line OP. A body that has a small total area of loop A is also likely to have a small area above the line OP. This means that a good boat-tailed afterbody can be formed by taking a complete streamline afterbody for which each of the loops A and B is as small as possible, and cutting off this body at some section P. The first requirement, that the boundary layer must not separate upstream of P, must also be satisfied, of course.

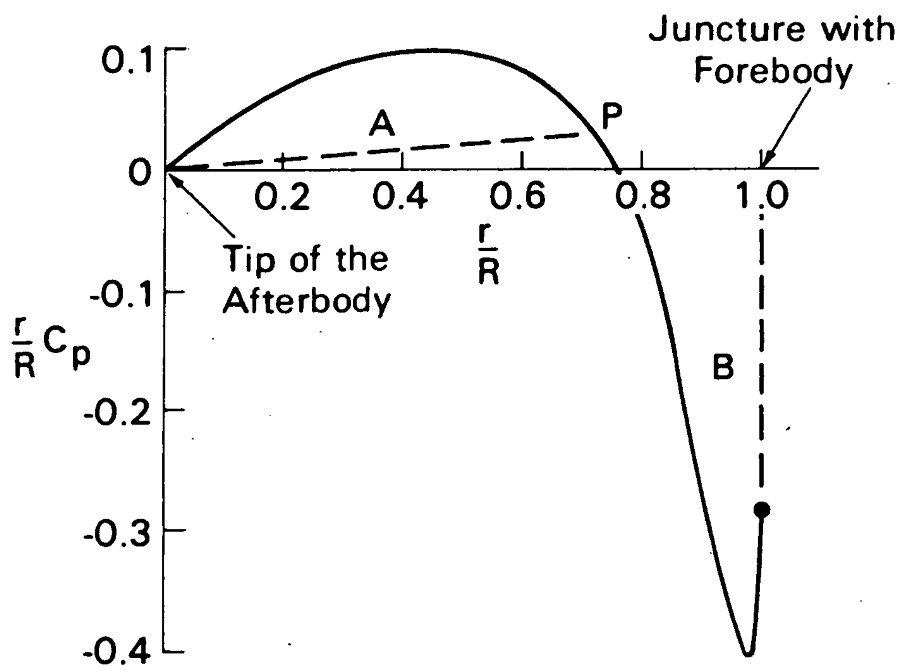

Fig. 10. Radial distribution of $(r/R)C_p$ for streamline afterbody in inviscid flow. r - local radius, R - maximum radius.

Examination of the pressure distributions from which the results shown in Fig. 7 were derived, shows that on the yawed body, the pressure falls as the tail is

approached, and then rises, in qualitative agreement with the curves of Fig. 8 for zero yaw. On the yawed body, both the fall of pressure and the subsequent recovery are greater on the windward side than on the lee side and, at stations very close to the base, the pressure becomes nearly uniform all round the body, probably because of the influence of the base. The favourable effect of a moderate angle of yaw, as shown in Fig. 7, indicates that the mean pressure at each section is modified in a favourable sense from the zero-yaw value shown in Fig. 8. As already noted, quite a small change in mean pressure at a section can have a significant effect on drag.

The large increase of axial-force coefficient that is shown in Fig. 7 for yaw angles above 15° is probably caused by a loss of pressure recovery due to separation of the boundary layer.

BOAT-TAILED AFTERBODIES WITH BOUNDARY LAYER CONTROL

The boat-tailed afterbodies that are most useful for practical purposes have a small overall length and a fairly large value of the angle β. Since one of the requirements already noted is that the boundary layer must not separate ahead of the base, it may be useful to consider whether some form of boundary-layer control (BLC) could be usefully employed to delay separation and hence allow greater freedom in design.

The easiest form of BLC to apply to a road vehicle would be a set of vortex generators, although this might be unacceptable for various practical reasons, including safety. Experience with aircraft and other applications suggests, however, that even the best arrangement of vortex generators would have only a marginal beneficial effect, and it seems likely that the best boat-tailed afterbody using these devices would be only slightly better than one without them.

Other possibilities to be considered are the use of BLC by suction or blowing to delay separation. Considering suction first, the best economy of power is obtained by sucking air from the boundary layer to reduce its thickness *before* the layer encounters any severe adverse pressure gradient. The suction flow and the power required will vary from zero, for a boat-tailed afterbody that is satisfactory even without BLC, to quite large values for short afterbodies with large values of the angle β. Thus no useful quantitative statements can be made without studying individual cases in detail.

It is known from studies of BLC in aircraft applications (e.g. Mair, 1966) that suction usually requires less power than slot blowing. Nevertheless, slot blowing has usually been preferred for aircraft because of the ready availability of high-pressure air from the compressors of the propulsion engines. For a road vehicle there would be no such reason to prefer blowing, since a special blower for the BLC would probably be required in any case, and suction would be the obvious choice because of its lower power requirement.

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The use of BLC in conjunction with a boat-tailed afterbody has been suggested here as a possibility, but, at present, there is little reason to think that this possibility is likely to be promising. Boat-tailed afterbodies have been shown to give large reductions of drag without BLC, and only detailed investigations can show whether there might be additional advantages in using BLC to give low drag with even shorter afterbodies.

CONCLUSIONS AND DISCUSSION

Consideration of known methods of reducing the drag of a blunt-based body of revolution has shown that a boat-tailed afterbody is much more effective than any other device that has been tried. Moreover, the boat-tailed afterbody can still give a good reduction of axial force at yaw angles up to about 15°.

A road vehicle must operate near the ground and cannot usually be axi-symmetric, although cylindrical road tankers for carrying liquids are of some interest. Much more experimental work will be needed before it is possible to design with confidence a practicable vehicle with a rear end shaped to take advantage of the boat-tail principle. The "Kamm back" that is already being used may be thought of as a shape with a roof-line as in Fig. 5, but with nearly straight boundaries at the sides and bottom. Such a shape may sometimes give a useful reduction of drag at zero yaw, but in a side-wind there is likely to be separation at the edges of the sloping afterbody and some of the beneficial boat-tail effect may then be lost. More experimental work is needed to develop practicable shapes based on the boat-tail principle, which give a low axial force, even when yawed.

The further complications of shear flow and turbulence in the atmospheric wind must also be considered.

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